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INFLUENCE OF WINGTIP DEVICES IN REDUCING INDUCED DRAG - A REVIEW

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ABSTRACT

Induced drag and the efforts to reduce it has been a continuous effort in the past decades. Many wingtip devices have evolved as a result of detailed research. Different winglets have reduced induced in different flight regimes. This paper documents the influence of winglets in the reduction of induced drag in the best possible way. The role of blended, raked wing grid, and spiroid winglets have been documented. It has been noted that different winglets have different efficiencies at different flight regimes and also the effect of different parameters of each winglet have been considered. The so called winglets provide an optimum reduction in drag created by the vortices at the tip of the aircraft wings. This paper also presents their theoretical significance by simultaneously keeping the aerodynamic characteristics into consideration.

KEYWORDS: Induced Drag, Blended Winglet, Raked Winglet, Wing Grid & Spiroid Winglets

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A Review Article

INTRODUCTION

The pressure difference between the lower surface and upper surface of the wing is one of the reasons why aircrafts are able to fly. And hence, the pressure at the lower surface of the wing must be greater than the pressure at the higher surface. Since air always flows from a region of lower pressure, a dangerous phenomenon is always imminent i.e. the air flows from the lower surface to the upper surface by making an end run around the wingtip. This twisting flow is known as wingtip vortex and has always been a disadvantage. The wingtip vortices create additional drag (lift induced drag), reducing the performance of the wing and increasing the cost for the operation. Thus, addition of winglets at the tip serves for enhancing the efficiency of the aircraft.

This paper discusses performance of various winglets used to reduce induced drag. Various winglets perform differently at different parameter and hence focus is on evaluating the different types of winglets and their efficiencies during various conditions.

STUDY OF BLENDED WINGLETS

The studies carried out by Pooja et al, Smith et al and Helal et al [1, 2, 3] have indicated that Blended winglets have exceptional characteristics which make them more efficient than any other winglet. Some of the characteristics which make these blended winglets perform better are:

- Increased L/D Ratio.
- Blended Winglet configuration reduces the wing induced drag and improved L/D ratio by 15-30%

compared with the baseline wing.

- Stall angle for blended winglet system is much higher than conventional system.
- At higher angle of attack, blended winglet system produces better Cl.

The findings of Doug McLean also emphasize on how the wingtip devices help in reducing the induced drag when blended winglets are used [4]. Alekhya Bojja et al [5] also confirms that the blended winglets are efficient when compared to other winglets resulting in less drag co-efficient and gives best result at 12 degrees angle of attack. Accordingly blended winglets have the following advantages such as:

- Negative Incidence and twist of the winglets improves L/D by reorienting the winglet lift vector forward and cancelling that part of drag.
- This finding when implied to a Boeing 737 resulted in a 7% drag reduction.
- Also, theoretical predictions had indicated that the configuration would only have a 1-2 % improvement and wind tunnel tests showed 2% drag reduction.

David Benett [6] picks up on the results carried out during the tests and the points out which are more precise and relevant when it comes to the context of Blended winglets. The following were the results when tests were carried out at their facility.

- The Cl/Cd ratio increases to about 3-15% along the angle of attack.
- The Blended winglet improves L/D by increasing it by 3-15 % compared to the wing without winglet.
- Reduces fuel burn.
- Minimises cost and saves millions of dollars per year.

Cui Peng et al [8] describe the various characteristics and predict the flutter characteristics for a transport wing with wingtip devices. Throwing light on the Blended winglet type, it is described as follows:

- Blended wingtip reduces wetted area.
- Blended wingtip reduces induced drag.
- It improves the overall L/D ratio.

Cui et al also elaborate upon the analysis on reducing the induced drag using the winglet at the wingtip by taking into account the blended winglet type and finally after reviewing and further analysis, finally arrive at the following conclusion:

- The Cd obtained for blended winglet is less for all angles of attack.
- The best Cd is obtained when the wing is kept at angle of attack of 12 degrees.

Summing it up for the Blended Winglet, a deep investigation is still required which can be further carried out. Better efficiency can be expected when it comes to blended winglets and it can be hoped that it has some room for slight improvement, when certain modifications be made on winglets and parameters such as cant angles, sweep and twist angles.

The following can be concluded for blended winglets.

- Blended Winglets improve the L/D ratio.
- The Cl/Cd ratio increases to about 3-15% during the flight.
- Blended winglets reduce wetted area and hence reduce induced drag.
- Where twisting and negative angle of incidence are concerned, the winglet improves L/D ratio by reorienting the winglet.
- Boeing 737 showed a 7% drag reduction.
- Stall angle for the Blended winglet system is much higher than conventional system.
- At higher angle of attack, blended winglet system produces better Cl.
- Implication of Blended Winglets in an aircraft can save several gallons of fuel per year and hence increase the efficiency.
- Reduces fuel burn.

STUDY OF SPIROID WINGLETS

Spiroid Winglets are one other type of winglets which also exhibit certain characteristics when it comes to reducing induced drag, which can account to as much as 30-40% of the drag in take-off and 85-90% in cruising conditions.

Vinay Kumar Bada et al [11] elaborate about the study which served as an initial investigation on the aerodynamic effects of Dual Feather winglets and Spiroid winglets configuration as a result a better winglet will be taken into consideration. The results presented in this study reveal certain parameters like velocity, dynamic pressure, static pressure and lift to drag ratio based on which comparison is done. Spiroid winglets have higher pressure and high velocities at different AOA's whereas Dual Feather winglets produce less pressure values and feasible velocities at different AOA's.

However, in Dual Feather winglets velocities seem to be more. Alternatively, comparing Lift to drag ratio, spiroid winglets have feasible L/D ratio. So they have concluded that spiroid winglets have paved a path for better and efficient aircrafts by reducing the induced drag, which is generated by the lift component and thus eliminated the chances of formation of vortices. There are various factors which showed improvement and is stated below:

- L/D ratio increases as a result of decrease drag.
- Less fuel burn.
- Reduction of vortices.
- Shorter runway usage for take-off.

Studies by Giftonkoil Raj et al [12] have shown the effect of drag in a transport aircraft and summarize that the lift-induced drag can make-up as much as 40% of the total drag at cruise conditions and 80-90% of the total drag in the take-off configuration.

Tung Wan et al [13] explains how different types of spiroid winglets, such as spiroid winglets with tip blown are been presented. A simple steady flow blowing at the wing tip can improve the lift-to-drag ratio. But implementation of blowing upon spiroid winglet is still questionable. Although blowing give us better results, the cost, complication, and the penalty we pay in thrust reduction sis large. Thus wing with only a spiroid winglet is highly recommended. Nikola N. Gavrilović et al [14] states that use of winglets in a commercial aircraft and further states that, the classical way of reducing induced-drag is to increase the aspect ratio of the wing. However, wing aspect ratio is a compromise of weight, structural load and operational constraints. The alternative solution is the use of aerodynamic structures at the end of the wing, which reduces the strength of the vortices, thus reducing the lift-induced drag. Different winglets on different aspects play their roles satisfactorily and hence we arrive at a certain points where we list the results as follows:

- It confirms that the concept of the closed-loop spiroid winglet is indeed able to reduce the induced drag and enhance aerodynamic efficiency.
- Implementation of blowing upon spiroid winglets is still questionable.
- Although, blowing gives us better results, but the cost complication and the penalty we pay in the thrust reduction seems large.
- Thus, wing with spiroid winglets is highly recommended

Joel E Guerrero et al [15] have shown that the performance of commercial aircrafts improve when using winglets. They have tested a spiroid wingtip, by adapting it to a clean wing. The performance of the wing with the spiroid winglet relative to the clean wing has been studied quantitatively and qualitatively. Suhail Mostafa et al [16] conducted a thorough research about spiroids by reviewing previously conducted research papers, and finally made a literature review based on the referred papers. From the literature review, it was found that FWD spiroids gave better results when compared to other types of winglets. Based on the initial knowledge gained, the author further proceeded by forming the different possible spiroid geometry configurations on the CAD software, Solid works, and analyzed the performance of each by conducting CFD analysis using ANSYS software. Apart from the spiroid configurations, the author also analysed the simple wing and simple winglet in order to make a performance comparison with spiroids.

The analysis was made in terms of Lift (lift coefficient CL), Total Drag (drag coefficient CD), Lift to Drag ratio (CL/CD), Endurance, Range and finally Induced Drag. Thus, this study clearly proved that spiroids are superior compared to other two wingtip configurations in terms of vortex suppression and overall drag reduction in terms of specific design requirements. The author proposes ideas that have a classical way of understanding and if applied with the help of spiroid winglets can yield better results. Below stated are the results which if implemented can be rewarding:

- The very first point talks about the aspect ratio of the wing and it says that the way to reduce the induced-drag in a wing is to increase the aspect ratio of the wing.
- The alternative solution is the use of aerodynamic structures at the end of the wing which reduces the strength of vortices, thus reducing the lift-induced drag.
- Other aerodynamic shapes are also tested by adopting them in a clean wing. Summing it up for the spiroid Winglets, from a technical point of view, it is imminent that there is a scope of improvement when spiroid winglets are considered. From the computational results, it can be said that the spiroid winglets can be efficient in

many ways. If some aerodynamic parameters are changed, it may yield better results in future and has a slight room for improvement. However, going by the present scenario, it can be efficient because of the following reasons.

- Spiroid Winglets saves 6-10% consumption of the overall fuel.
- It accounts for 5% induced drag reduction.
- It enhances the L/D ratio.
- It overall enhances the aircraft efficiency.
- Less vortex formation at the wingtips.
- Savings of million dollars in fuels.
- Reduced fuel burn.

STUDY OF RAKED WINGLETS

Raked winglets are another category of winglets which are also considered when it comes to induced drag reduction. These winglets also possess characteristics which are sufficient enough to minimise vortex formation at the wing tips and hence reduce the overall drag.

A. Abbas et al [17] have presented the idea through which we can aircraft performance by testing various parameters of an aircraft. Joel F Halpert et al [18] discusses the Aerodynamic optimisation and evaluation of a 'KC-135R' Winglets, Raked wingtips and wingspan extension, keeping in mind the findings made by the authors and the wind tunnels test carried out. In Phase I, the first series of testing found that the nominal size winglet with a root chord that was 65% of the wingtip chord was the optimal size for the winglet plan form. Although the 110% sized winglet with a root chord 71.5% of the wingtip chord had almost identical improvements for lift over drag versus angle of attack, the nominal size did have a higher value associated with maximum range. The second series showed that the nominal cant angle of 15° was the optimal cant angle. Although other winglet cant angles, had very similar values for lift over drag, the differences associated with maximum range were much more pronounced and the nominal cant angle was clearly superior. The third stage of testing showed that the nominal toe angle of -4° was the optimal toe angle for the winglets. The nominal winglet was far superior to the other winglets with some of the other configurations actually decreasing the maximum range with only slight increases in endurance. This research showed why it is important to optimize the winglet design for an aircraft since using a non-optimal size, cant, or toe angle has the potential to degrade performance.

Wind tunnel tests were run on a range of Mach numbers (0.2, 0.3, and 0.4), winglet sizes, and cant angles (5-25 degrees).

- While the optimal winglet offered, increases in endurance and range potential of 5.62% and 3.55% respectively, a raked wingtip with 20 degrees of additional leading edge sweep offered increase of 8.32% and 4.69%.
- Meanwhile the wingspan extension offered increase of 7.02% and 4.21%.
- Wingtip modifications reduced fuel burn by 8%.

Swagat Prasad Das et al [10] presented the influence of Reynolds numbers for two different wingtip configurations (such as, sweptback tapered wingtip and the single slotted raked wingtip) and were investigated at different angles of attack by using the numerical simulations in FLUENT. The flow structure of a tip vortex behind a sweptback and tapered NACA 0015 wing with an AR of 3.654 was investigated for three different Reynolds numbers (i.e. 1.81x105, 3.12x105 and 4.16x105) at different angles of attack for the two different configurations (sweptback-tapered wingtip and single slotted raked wingtip).

- The tip vortex characteristics of two different wing geometries at various angles of attack are shown for different Reynolds numbers.
- The numerical results that are obtained by using CFD code show a good agreement with the experimental results.
- The effects of Reynolds number on the aerodynamic characteristics are found at higher angle of attack but not at lower angle of attack.
- The increase in aerodynamic efficiency is more for single slotted raked wingtip as compared to sweptback tapered wingtip, which ultimately leads to reduction of induced drag.

WING GRID

Wing Grid, are the other type of winglets which show certain characteristics and also play an important role in induced drag reduction. They show better aerodynamic characteristics and have been proved in many fields. U La Roche et al [7, 19] show that the maximum effect results by application of wing grids in rectangular wing, while testing the same on the elliptical wing there was no substantial gain. The following conclusions were made:

- The wing grid has a negative effect on flight performance at low speeds.
- The flow over it tends to separate before the wing generates a rectangular lift distribution.
- The critical flow regime in which the Reynolds number over the grid is sufficiently large and the wing grid effect reduces induced drag was not reduced.
- The data does however imply that at high speeds the wing grid effect may be present at low cruising angles of attack.

Mohammad Reza Soltani et al [20] describes a novel device to reduce induced drag. Hence, it also describes how it has been advantageous in reducing the active drag by using the winglets. Wind tunnel tests have been carried out and conclude that:

- Wing grid model reduces the vortex formation at the wing tip by reducing the core diameter of the vortex.
- Lift generated by wing in the normal situation is not equal to the calculated value but by using wing grid model it can be nearly equal to the calculated lift.
- For high value of Reynolds number there is massive loss in energy and this model can’t explain about that.
- The elliptical wing used is not sufficient for the wingtip to reduce the vortex formation due to less chord length at the tip as compared to the rectangular wing with the wing grid.

CONCLUSIONS

In the above mentioned winglets, they all seem to reduce induced drag and hence increasing the efficiency of the aircraft. Several winglets were and following were the conclusions.

- The Blended wingtips have been advantageous at take-off conditions.
- Spiroid Winglets show different characteristics than any of the other winglets and have proved to reduce the induced drag by increasing the lift curve slope.
- Raked winglet don't generate lift rather they reduce drag in a special way, by redirecting wingtip drag farther outboard and aft of the wing and also redistributes the lift along the wing. The result is that they work very well in ultra-cruise segments. They don't depend on wing angle of attack, and reduce fuel consumption when engine thrust is already set to cruise.
- Wing-grid on the other hand have not proved to be so commendable as it does not show better aerodynamic properties and is limited therefore in its usage. More research on wing grids could help optimize their usage in the aerospace industry.

REFERENCES

1. *Pooja Pragati, Sudarsan Baskar, Aerodynamic Analysis of Blended Winglet for Low Speed Aircrafts, Proceedings of the World Congress on Engineering, 2015, Volume II, July 1-3 2015.*
2. *M. J. Smith, N. Komerath, R. Ames, O. Wong, Performance analysis of a wing with multiple winglets, AIAA- 2001-2407.1-10.*
3. *Hesham S. M. Helal, Essam E. Khalil, Osama E. Abdellatif, Gamal M. Elhariry, Aerodynamic Analyses of Aircraft- Blended Winglet Performance. IOSR Journal of Mechanical and Civil Engineering (IOSR – JMCE), Volume 13, 65-72. May – June 2016.*
4. *Doug McLean, Wingtip devices: What they do and how they do it. 2005 Boeing Performance and Flight Operations Engineering Conference, Article 4, 4.2-4.18.*
5. *Alekhya Bojja, Parthasarathy Garre, Analysis on Reducing the Induced Drag Using the Winglet at the Wingtip, International Journal of Engineering Research & Technology (IJERT), Volume – 2, December 2013.*
6. *David Benett, A new approach to reducing induced drag, Final Report Fall 2001, December 11, 2001.*
7. *U. La Roche, S. Palffy. WING-GRID – a novel device for reduction of induced drag on wings, ICAS-96-2.10, 2303 – 2309, 1996.*
8. *Cui Peng, Han Jinglong. Prediction of flutter characteristics for a transport wing with wingtip devices, Aerospace Science and Technology, Volume 23, Issue 1, 2012, Pages 461–468*
9. *Swagat Prasad Das, Sangram KeshariSamal, Radharaman Dalai, Manas Ranjan Padhi, Reduction of Induced Drag by Single Slotted Raked Wingtip,. International Journal of Innovative Research in Science, Engineering and Technology. Vol – 4. 1008-1017, 2015*
10. *William Freitag, E. Terry Schulze, Blended winglets improve performance, Boeing, http://www.boeing.com/commercial/aeromagazine/articles/qtr_03_09/article_03_1.html*
11. *Vinay Kumar Bada, Kumari Monika, Akram Hussain. Md, Praveenkumar. chikoti. CFD Analysis and Comparison of Spiroid and Dual Feather Winglet, International Journal of Engineering Research, Vol -5, 657- 661, 2016.*

12. *W. GiftonKoil Raj, T. AmalSeba Thomas. Design and Analysis of Spiroid Winglet. International Journal of Innovative Research in Science Engineering and Technology, Volume – 4, 1139-1147, March 2015.*

13. *Tung Wan and Kuei- Wen Lien, Aerodynamic Efficiency Study of Modern Spiroid Winglets, Journal of Aeronautics, Astronautics and Aviation, Volume – 41, 23-30, 2009.*

14. *Nikola N. Gavrilović, Boško P. Rašuo, George S. Dulikravich, Vladimir B. Parezanović, Commercial Aircraft Performance Improvement Using Winglets, FME Transactions Volume – 43, 2015.*

15. *Joel E. Guerrero, Dario Maestro, Alessandro Bottaro, Biomimetic spiroid winglets for lift and drag control, Comptes Rendus Mecanique, 67-80, 30th December 2011.*

16. *Suhail Mostafa, Shyam Bose, Archana Nair, Mansoor Abdul Raheem, Thasneem Majeed and Atiqur Mohammed, Young Kim, A parametric investigation of non-circular spiroid winglets, EPJ web of conferences, EDP Sciences, 1-5, 2014.*

17. *Abbas, J. de Vicente, E. Valero, Aerodynamic technologies to improve aircraft performance, Aerospace Science and Technology, 100-132, October 2012.*

18. *Joel F. Halpert, Daniel H. Prescott, and Dr. Thomas R. Yechout and Michael Arndt, Aerodynamic Optimization and Evaluation of KC135R Winglets, Raked Wingtips, and a Wingspan Extension. 48th AIAA Aerospace Sciences Meeting Including the New Horizons Forum and Aerospace Exposition, 1-11, Jan 2010.*

19. *U. La Roche and H. L. La Roche. Induced Drag Reduction using Multiple Winglets, looking beyond the Prandtl- Munk Linear Model, American Institute of Aeronautics and Astronautics, 1-21, 2004.*

20. *Mohammad Reza Soltani, Kaveh Ghorbanian, Mehdi Nazarinia, Experimental Investigation of the Effect of Various Winglet Shapes on the total pressure distribution behind a wing, 24th International congress of the aeronautical sciences, 1-11, 2004.*